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High Brilliancy – Which Effects Do Small Foci Have On Secure and Efficient Welding?

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Abstract

The main focus of the article is on the reflection of welding with small foci. Questions regarding efficiency, the chance of increasing speed and thus reducing cycle time in production are particular key subjects. Furthermore, examples of applied parts will be presented and evaluated. Moreover, a correlation will be shown between the process and the achieved mechanical properties on the example of the tensile shear test.

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1. Introduction

The fiber laser as a beam source of highest brilliance has meanwhile been established in the field of laser material processing, and with the achievement of the maturity phase – unimaginable not so long ago – high power densities can be achieved. Whereas the revenue and market share within the field of laser material processing has risen fast in the beginning of 2008 [1], the laser business was also hit by the effects of the international recession. With 5.32 billion US Dollars, laser sales were about 24 percent lower in 2009 than in the previous year and therefore approximately on the level of 2003. The fiber laser business had to face a loss of revenue of 21 percent for the first time [2]. In order to realize the prognosticated growth rates of 11.1 percent for the current year, the use of higher brilliant beam sources and the resulting advantages will have to be in the focus more than ever to show possibilities to raise productivity securely and efficiently.

From the user's point of view, high beam quality can be transformed into a small focus and/or a small divergence angle and therefore into a large operating distance. In that way, a high aspect ratio can be achieved in sheet metal manufacturing, and auxiliary process time can be reduced by fast positioning over large operating distances. Prerequisite for a secure and efficient increase in productivity is a clarification of the use of small welding foci which is absolutely possible. On the one hand, small foci have an influence on manufacturing tolerances, gap

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bridgeability, Rayleigh length and focal position offset tolerance during both preparation and welding process, and on the other hand, they allow the specific guidance of heat input into the part. With an accordingly useful combination of these properties, efficiency and the chance of increasing speed and thus reducing cycle time should be investigated to achieve a reduction of costs in order to raise the attractiveness of laser sources with high brilliancy.

2. Welding with Small Foci

Particularly in the ancillary industry around the car industry, the production of household machines or the food industry, welding seam lengths of more than one meter are not unusual. Compared to very short weld seam lengths as they are used e.g. for welding bodywork (step joint), we see a high potential and the necessity to increase productivity by increasing welding speed to remain economically competitive.

Many parts having to be joined such as oil sumps, sidewalls or steel doors are produced by cold forming out of mild steel which constitutes the major contingent within the market segment of cold formed sheet metal products. Especially DC01 is used for simple canting and drawing operations. With a tensile strength of 270 to 410 MPa and 0.2 percent yield strength of 140 to 280 MPa, the steel is really well formable, and due to its chemical consistence exhibits good weldability [3]. The welding trials were performed as lap joints with 0.88 mm thick metal sheets measuring 83.5 mm x 45 mm so as to make a statement towards the mechanical-technological property profile with the help of a tensile shear test (test speed 10 mm/min, specimen breadth 45 mm). For the welding trials a multimode fiber laser by the company IPG was provided as a beam source of higher brilliance having an output power of one kilowatt. A welding head from the company HIGHYAG with a focal length of 200 mm was used with different fiber diameters of 50, 100, 200 and 400 μm . With the plotted beam parameter products by corresponding feeding and/or process fibers in Table 1, the laser provides good preconditions for processing with small foci.

Table 1. Beam parameter product by different fiber diameters with a fiber length of 15 meters

Fiber	Beam parameter product in mm-mrad
Feeding fiber 50 μm	1.7
Process fiber 100 μm	2.9
Process fiber 200 μm	6.1
Process fiber 400 μm	16.2

Due to the use of the same focal length, the flank angles for different spot diameters are equal. By dividing the fiber diameter by two, the intensity in the focus increases by factor four which is reflected clearly in process efficiency. The energy effort remains constant over the power, whereas energy requirement increases exponentially with decreasing intensity [4].

There are different requirements with regard to the mechanical-technological property profile depending on the load cases related to the joined parts. For laser-based material processing of sheet metal, spot diameters of 400 to 600 μm have been established. Different requirements concerning the seam are set depending on the application. White goods or metallic furniture for example are mainly exposed to static loads. By way of a specific design of the weld seam profile, appropriate strength profiles can be achieved. Next to the effects of small foci on tensile force and working spot, geometry is important depending on different load cases. Thus, in addition to linear welds with a length of 30 and 15 mm, S-shaped and circular seams with a length of 30 mm and radii of approximately 5 mm were generated. (Fig. 2).

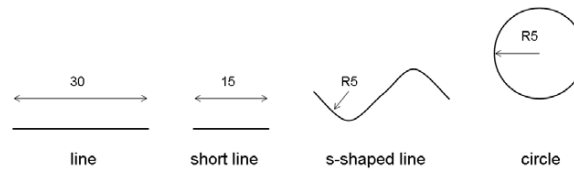


Fig. 1. Schematic drawings of seam geometries

The definition of the seam length is based on comparative investigations on resistance spot welds where the diameter of the spot is about 4.5 mm. The process is often used due to low acquisition costs and easy handling. Expensive clamping jigs to ensure gap free joining are not needed.

The qualitative welding criterion for all trials was a fully homogeneously built seam root to guarantee a secure welding process. In order to provide security for the process results, the respective combinations of parameters were welded at least three times, and a mean value was calculated. The force-transverse crosshead displacement graph for welding a line of 30 mm with a 50, 100, 200 and 400 μm fiber diameter is shown in Fig. 3. The welding speed with a fiber diameter of 50 μm was 60 mm/s, 55 mm/s with a diameter of 100 μm , 40 mm/s with a diameter of 200 μm and 13 mm/s with a fiber diameter of 400 μm . Exceeding these velocities, reproducible homogeneous seam roots could not be welded.

When welding with a fiber diameter of 50 μm , 100 μm as well as 200 μm , a failure of the link layer could be observed. (Fig. 4 a). The specimens unbuttoned after choosing the bigger fiber diameter of 400 μm (Fig. 4 b).

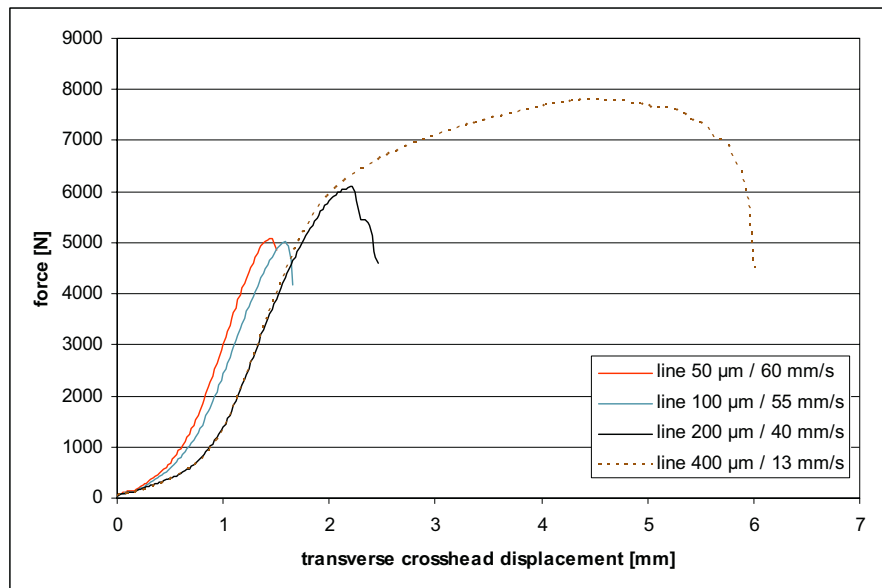


Fig. 2. Force-transverse crosshead displacement graph for welding a line with 30 mm length with different fiber diameters

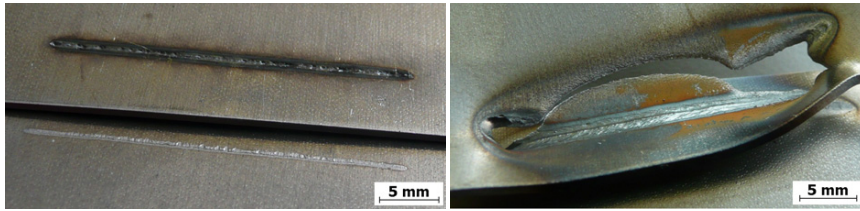


Fig. 3. (a) Failure of the line weld seam with a length of 30 mm and (b) unbuttoning of the specimen

There is not much of a difference between the results for maximum tensile force and work for specimen welded with 50 and 100 μm fiber diameters. An increase of the values can only be registered with a fiber diameter of over 200 μm . Whereas the values of maximum tensile force for welding with 200 μm fiber diameter is 20 percent higher compared to seams welded with 50 and 100 μm fiber diameters, it is increased by more than one third when using the 400 μm fiber diameter. With increasing fiber diameters, the work raises more notably in comparison to the maximum tensile force. This increase is also reflected in seam and root breadth.

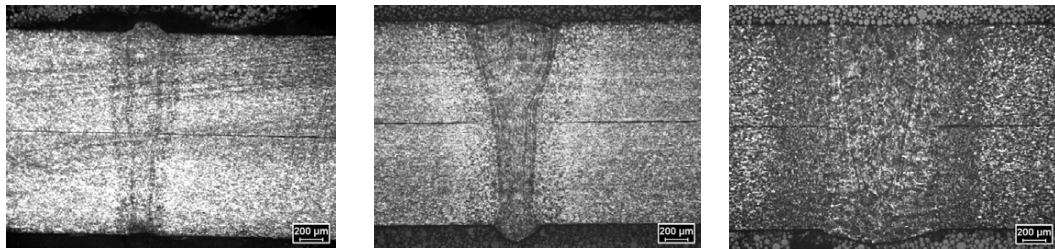


Fig. 4. (a) Formation of the weld seam welded with a fiber diameter of (a) 50 μm , (b) 200 μm and (c) 400 μm

Whereas the values for the seam and root breadth are within a range of 450 μm and/or 250 μm , the values increase abruptly by a factor of two when welding with a 200 μm fiber diameter (Fig. 5 a and b). From this intensity threshold upwards, there is no change in seam breadth when changing the spot size from 200 to 400 μm (Fig. 5 c).

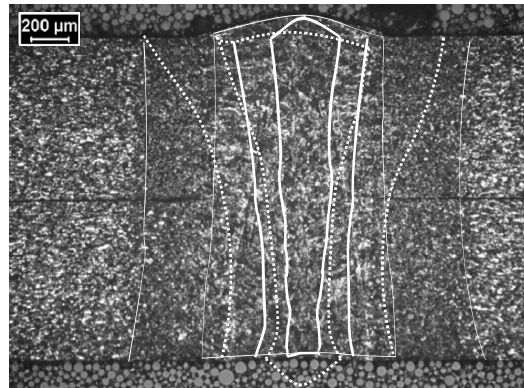


Fig. 5. Comparison of the formation of the weld seam and HAZ welded with fiber diameters of 50 μm (thick line), 200 μm (broken line) and 400 μm (thin line)

Only the seam root expands. Strong distinctions in the dimension of the heat affected zone (HAZ) can be found there. The HAZ is larger because of the lower speed when welding with a 400 μm fiber diameter, and thus the danger of distortion increases. In this case, the directed heat input with small foci brings visible advantages (Fig. 6).

The specimens welded with circular geometry show a similar behavior (Fig. 7). Both resistance spot weld and seam welded with a 400 μm spot diameter “unbuttoned” (Fig. 8 b and c). Due to the higher strength of the weld seam and the force flow, the surrounding material was deformed until it cracked after reaching the maximum tensile force. The seam welded with a 100 and 200 μm fiber diameter failed as well (Fig 8 a).

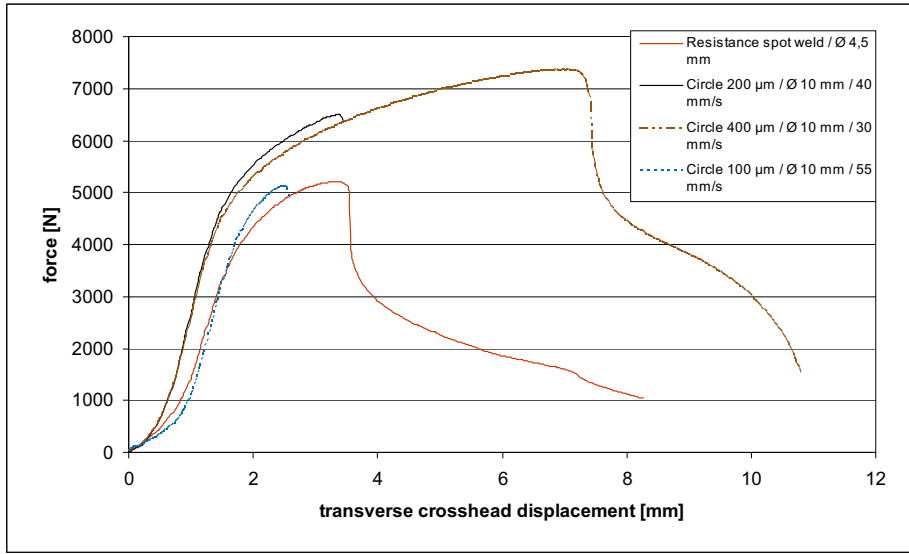


Fig. 6. Force-transverse crosshead displacement graph for welding a circle with ca. 30 mm seam length at different fiber diameters and for a resistance spot weld

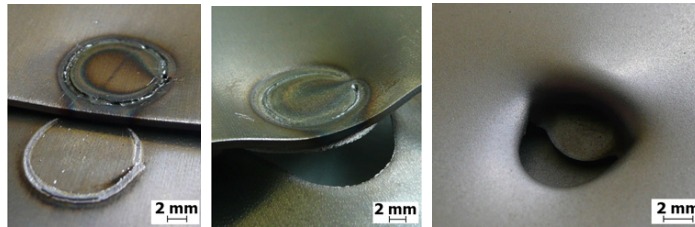


Fig 7. (a) Failure of the circular weld seam, (b) and (c) unbuttoning of the specimen for circular seam and resistance spot

A large amount of work caused by deformation can be absorbed due to the unbuttoning. The values for maximum tensile force as well as the work are lower for welding a line. An improved flow of force based on the circular geometry and the smaller force impact area can be considered a reason for this circumstance. The tensile force for seams welded with a 50 and 100 μm fiber diameter and the resistance spot weld are on the same level.

The effects of small foci on tensile force and work for different welding geometries are summarized in Fig. 9 and 10. The values are related to the results welded with a 400 μm fiber diameter, with a maximum tensile force of 8,500, 5,250, 8,000 and 8,000 N, as well as a work of 48, 8, 37 and 71 Nm for welding the line, short line, S-shaped line and circle with a focal position on the lower side of the work piece (- 1.78 mm). Compared to the welding of a

line, the improvement achieved by using an S-shaped line is marginal. There is not much of a difference between the results welded with a 50 and 100 μm fiber diameter.

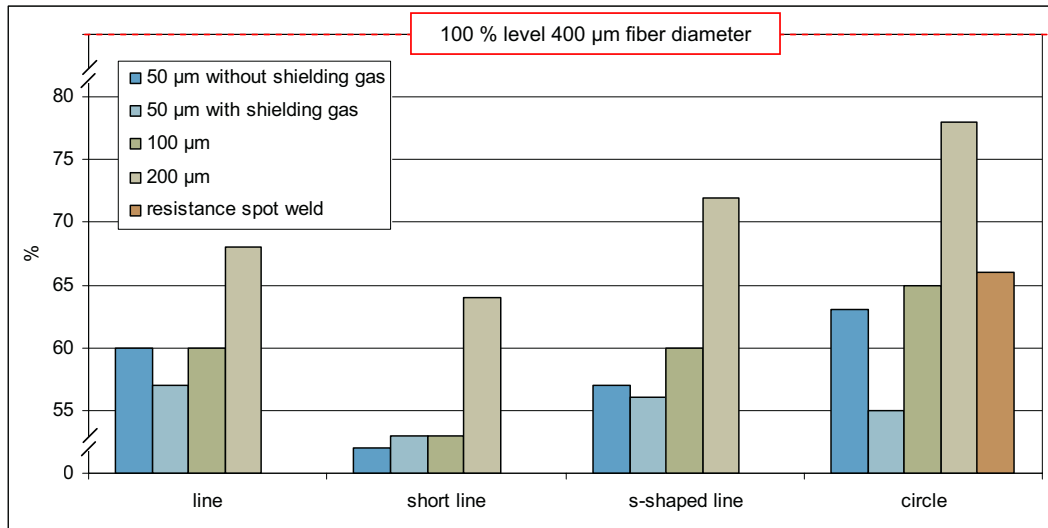


Fig. 8. Comparison between the tensile force of different seam geometries welded with different fiber diameters and values found for a fiber diameter of 400 μm

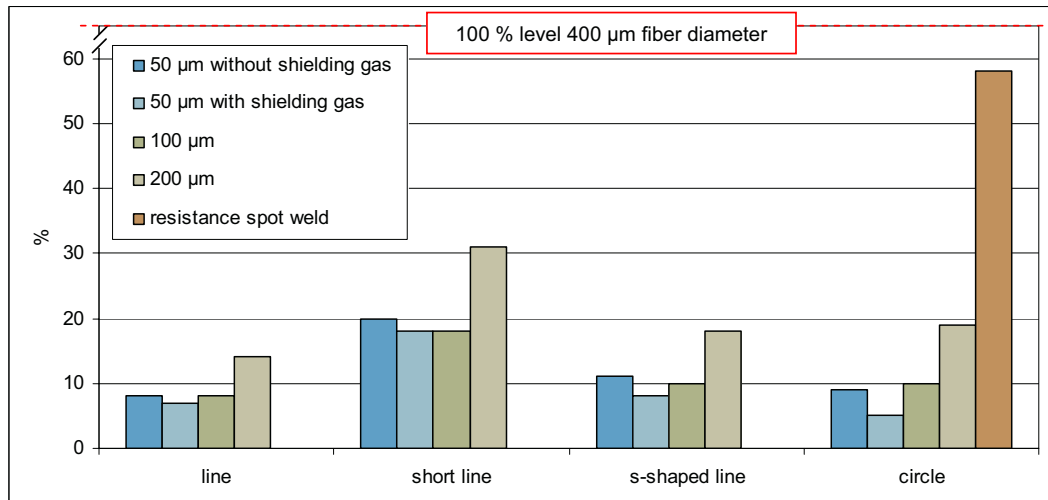


Fig. 9. Comparison between the work of different seam geometries welded with different fiber diameters and values found for a fiber diameter of 400 μm

The presented results can only be taken into consideration when the fiber diameter equals the fiber core diameter. When focusing on smaller foci, the effect of the flank angle has to be considered as well as the fact that the power

density distribution by way of high focusing in beam propagation direction does not contribute significantly to the creation of a weld pool [4].

Within the scope of the investigation, two more process parameters were examined apart from weld seam geometry. In order to estimate the impact of shielding gas (in this case argon) on tensile force, work, seam and root breadth, the results of the circular and linear joint geometries by welding with a 50 μm spot and a focal position on the bottom side of the part (0 percent) were compared. Both seam breadth and root breadth are larger when welding without shielding gas.

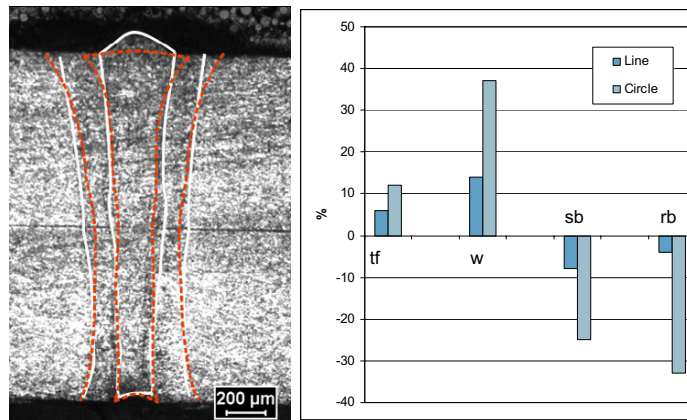


Fig. 10. (a) Comparison between the seam geometry with (---) and without shielding gas welded with a fiber diameter of 50 μm , 60 mm/s, focal position -1,78 mm, 1 kW; (b) Comparison of the maximum tensile force (tf), work (w), seam breadth (sb) and root breadth (rb) for welding a circular and a linear geometry using shielding gas

All in all, the load-bearing cross sectional and root area is bigger (Fig. 11 a and b). Tensile force is 6 and/or 12 percent higher, and work is 12 and/or 37 percent higher welding a line or circle when the joint is welded without shielding gas. Whereas the maximum tensile force for circles and lines welded without shielding gas are nearly on the same level with values of 5,100 and 5,000 N, the deformation work differs notably with values of 3.8 and 6.7 Nm.

With respect to productivity it is important which kind and degree of deformation the part is exposed to.

It was proven that weld seam profiles can be created with small foci meeting the mechanical-technological requirements of parts which are exposed mainly to static loads with respect to tensile force and work.

Due to the higher intensity when welding a weld seam with homogeneous root formation with smaller foci, higher processing speeds can be achieved, and the amount of heat influence on the basic material can be reduced.

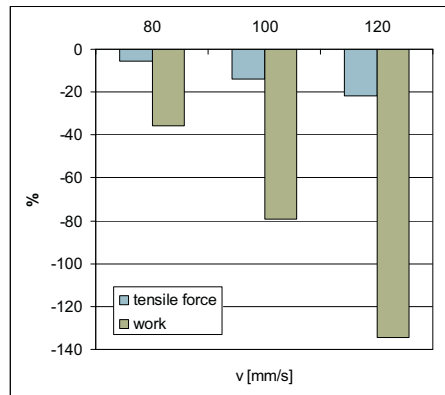


Fig. 11. Comparison of maximum tensile force and work for increasing speed with a seam welded with 60 mm/s, focal position 0, seam geometry: line

The increase in speed has a particularly significant influence on the amount of work which can be absorbed due to deformation (Fig. 12). The work decreases disproportionately compared to the maximum tensile force. By choosing the right processing speeds, cycle time can be reduced and the related productivity can be increased. This fact becomes evident when looking at a seam with a supporting cross-section of ca. 16 mm² (Fig. 13).

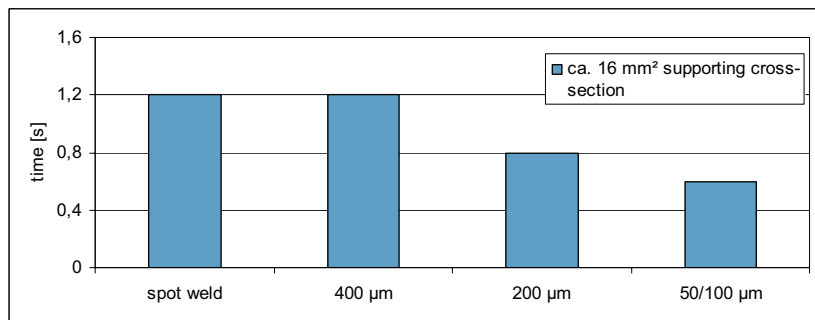


Fig. 12. Comparison of welding time required to weld a seam with a supporting cross-section of ca. 16 mm²

Whereas the time required for the resistance spot weld is about 1.2 seconds, the time for welding with a focus diameter of 100 µm amounts to 0.6 s and is only half as long. By reducing the welding time by 0.4 seconds and using a focus diameter of 200 µm, the tensile force can be increased. An increase of both tensile force and work can be achieved by using the 400 µm fiber diameter. Although the welding times are on the same level, the tensile force is 33 percent higher and the work nearly twice as high as for the resistance spot weld.

3. Application Examples

The potential of using small foci for secure and efficient welding can be demonstrated with the help of two examples. On the one hand, resistance welded spots on steel doors should be replaced by line seams and on the other hand, pore sensitive materials should be welded.

For the production of steel doors using mild steel for furniture or other mobile goods, high stiffness in combination with low weight is crucial. In order to achieve the required stiffness, bars are built in or the sheet metal is formed into rectangular profiles at the edges. Afterwards the sheet metal is tack or spot welded. The spot weld is typically generated by way of resistance welding. In order to guarantee the torsional stiffness of the door, a lot of

spots have to be set, the maximum of allowed work being much higher than the work really needed. By using small foci at high velocities, a disproportional increase of speed reduces cycle time by at least 50 percent. Furthermore, heat affection can be minimized visibly due to the directed heat input (Fig. 14).



Fig. 13. Comparison of resistance welded spot and laser weld seam at the inner side of a steel door

Casting provides the unique opportunity to produce complexly formed parts near net shape. Aluminum cast material is often used in the car industry because of the lightweight construction potential on the one hand and good castability on the other. Especially in casing construction, complicated geometries with undercut are manufactured as multipart cast components. These components have to be joined after the casting process. The liquid solubility of aluminum for hydrogen is high but decreases abruptly when it solidifies. There is only a limited chance for the hydrogen to exhaust, thus pores being created in the aluminum. When the part is locally heated in excess of the melting temperature after the casting process - as it is the case for fusion welding - hydrogen will be released in an eruption-like manner because pores which were closed are opened again and the pressure caused by high temperatures is high. As a consequence, aluminum cast parts are known for their poor or moderate fusion weldability. One possibility lies in joining the components with the help of pressure welding processes allowing a substance-to-substance bond below the melting temperature. The use of small foci can support the laser process to the extent that only a small portion of material is being heated. Thus, the pores play a secondary role. Figure 15 shows the result of welding an aluminum casted part. The processing of the part was stable without ejects.

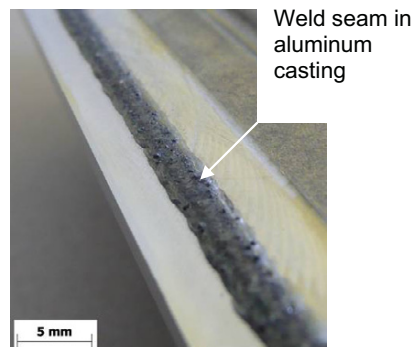


Fig. 14. Processing result: welded seam surface with aluminum casting

4. Summary

Rising energy and material costs increase the process costs and thus the economical pressure on companies. In order to remain economically competitive, it is important to find efficient and secure joining technologies. A basic approach is welding with small foci. Since processing with small foci is not yet completely clarified, it was our aim to investigate the effects of small foci on efficiency, increase in speed and thus reduction of cycle time as well as on the mechanical-technological property of the joint.

To make a statement as to the effects of shielding gas on the weld seam, trials with a 50 μm fiber diameter with and without argon were carried through. Afterwards tensile shear tests were performed. Both maximum tensile force and deformation work are higher without shielding gas. Furthermore, a suitable weld seam geometry has to be chosen with respect to the right load case. In addition to geometries such as a line and an S-shaped line, circular geometries were welded too. All trials performed with a circular geometry showed increased maximum tensile force and work. Investigations on the effect of different foci on maximum tensile force and work showed an equal level of seam results welded with 50 and 100 μm fiber diameters in all geometries. With a 200 μm fiber diameter an increase of the values can be observed. The comparative investigations on seams welded with a 400 μm fiber diameter and resistance welding resulted in “unbuttoning” and failure of the base material. While tensile strength and deformation work of seams welded with bigger foci are high, it is important to take into account which kind of deformation the part is exposed to. Thus an increase of productivity by sufficient maximum tensile force and low possible deflection can be achieved and the cycle time can be reduced by half. Feasibility was proven by two application examples.

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